Automatic Design of Missions to Small Bodies

Candidate Selection and Feasibility Studies

Javier Roa, Alan B. Chamberlin, Ryan S. Park, Anastassios E. Petropoulos, Paul W. Chodas, Damon Landau, Davide Farnocchia

Jet Propulsion Laboratory, California Institute of Technology

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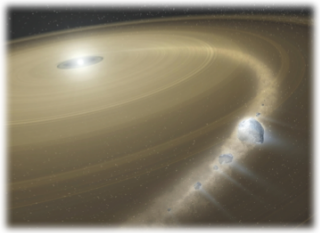
Orbit Determination

The AUTO System

COLLECT OBSERVATIONS → NEW ORBIT SOLUTION → STORE IN SMALL-BODY DATABASE → END USER



Solar System Dynamics

cneos Center for Near Earth Object Studies

HORIZONS system

Pre-computed Solutions

Filter for rapid candidate selection:
Physical + *orbital* + ***mission-design*** *parameters*

Interactive Interface

Single-body analysis, access to latest orbit solutions.

Impulsive missions + Low-thrust ΔV estimates

Mission Design System

Operation Modes

Query Mode: all bodies

- Pre-compute impulsive, optimal mission opportunities.
- Phase-free low-thrust ΔV estimate.
- Stored in the Small-Body Database for fast lookup, updated periodically.
- Combined query: **orbital** + **physical** + **mission-design** parameters.

Framework for rapid candidate selection

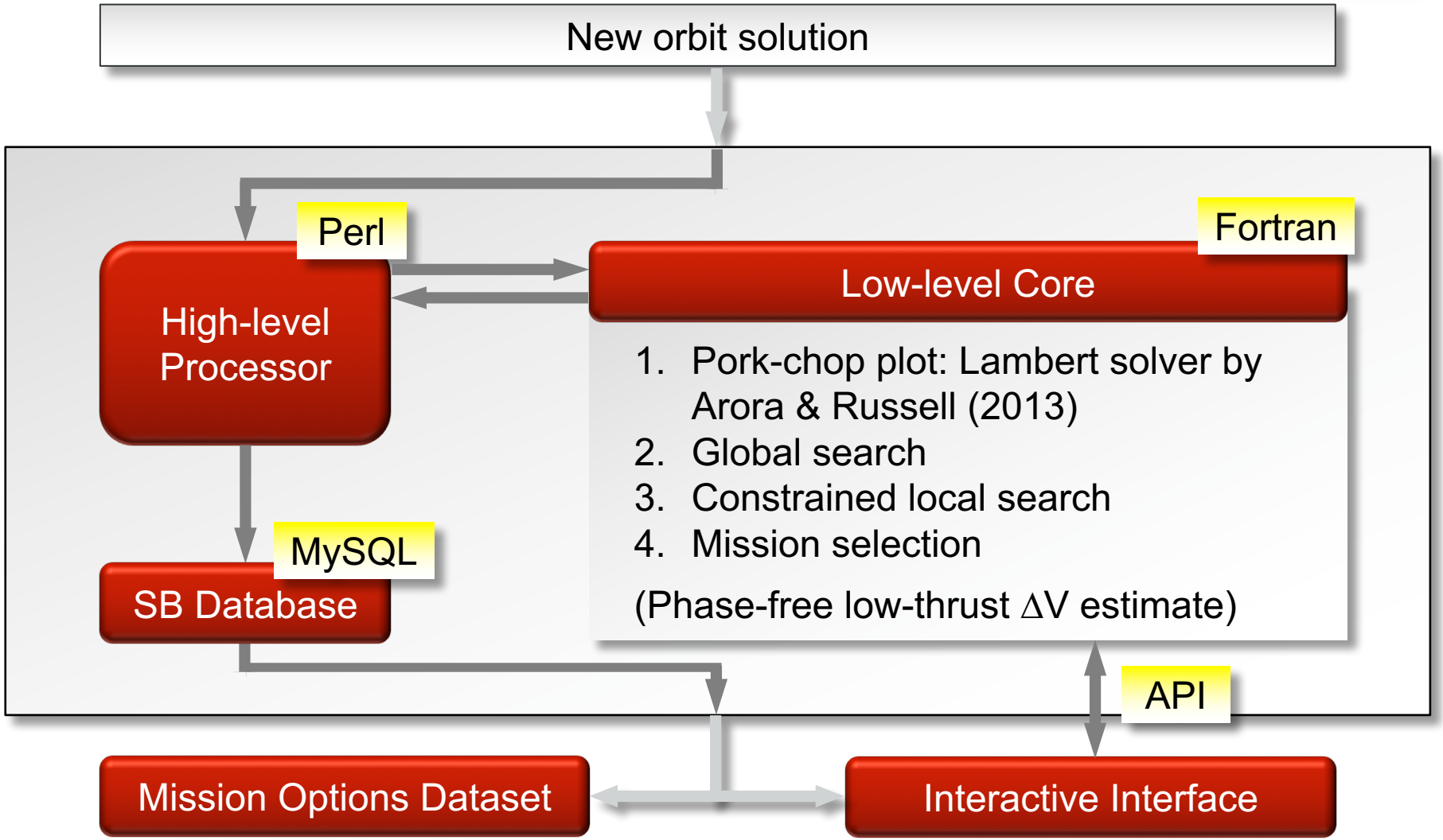
Detailed Mode: each body

- **Interactive interface:** More in-depth analysis of each candidate body.
- Preliminary mission selection.
- Access to latest orbit solution + newly discovered bodies.

Preliminary analysis of feasible solutions

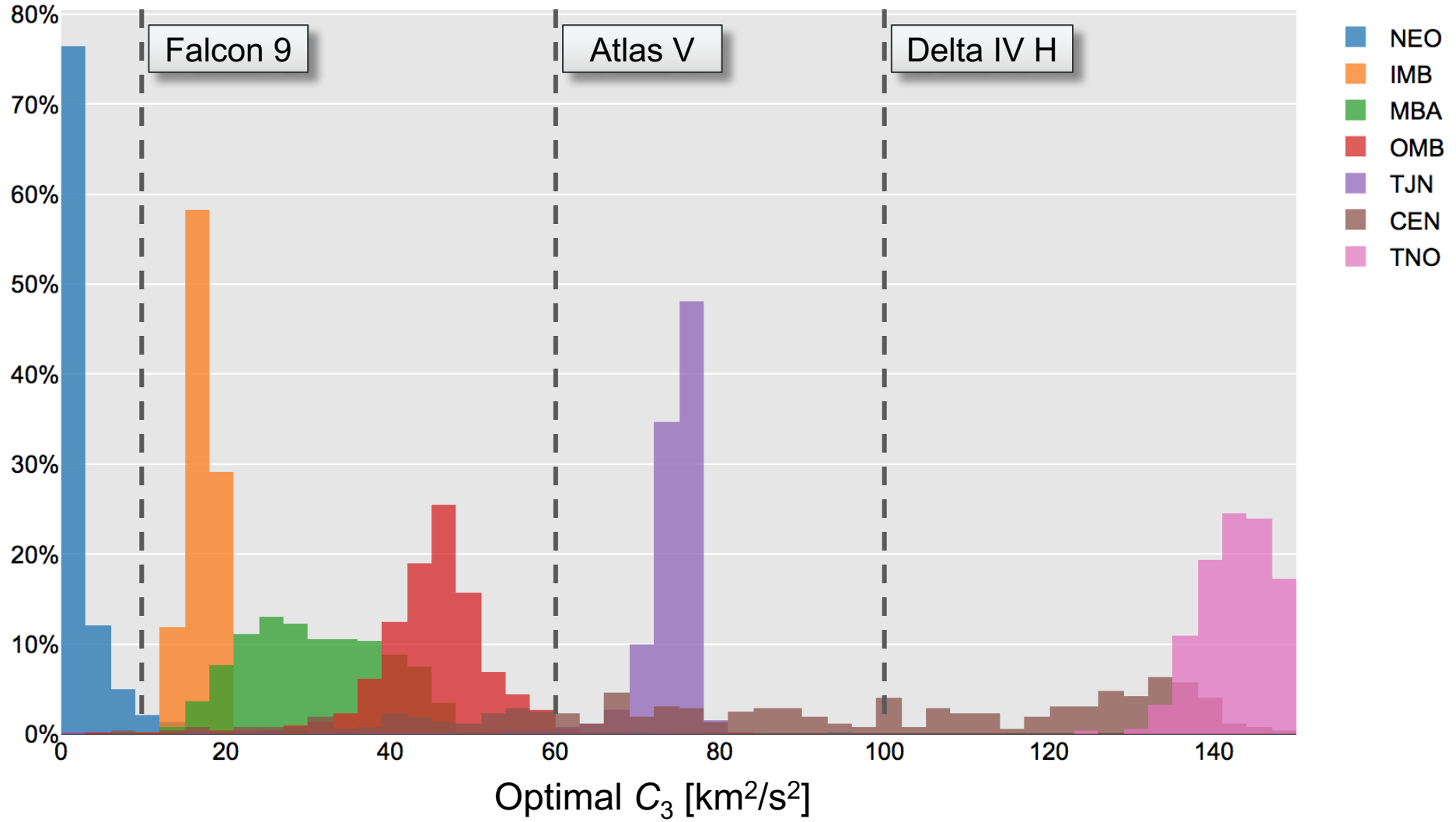
Mission Design System

System Overview



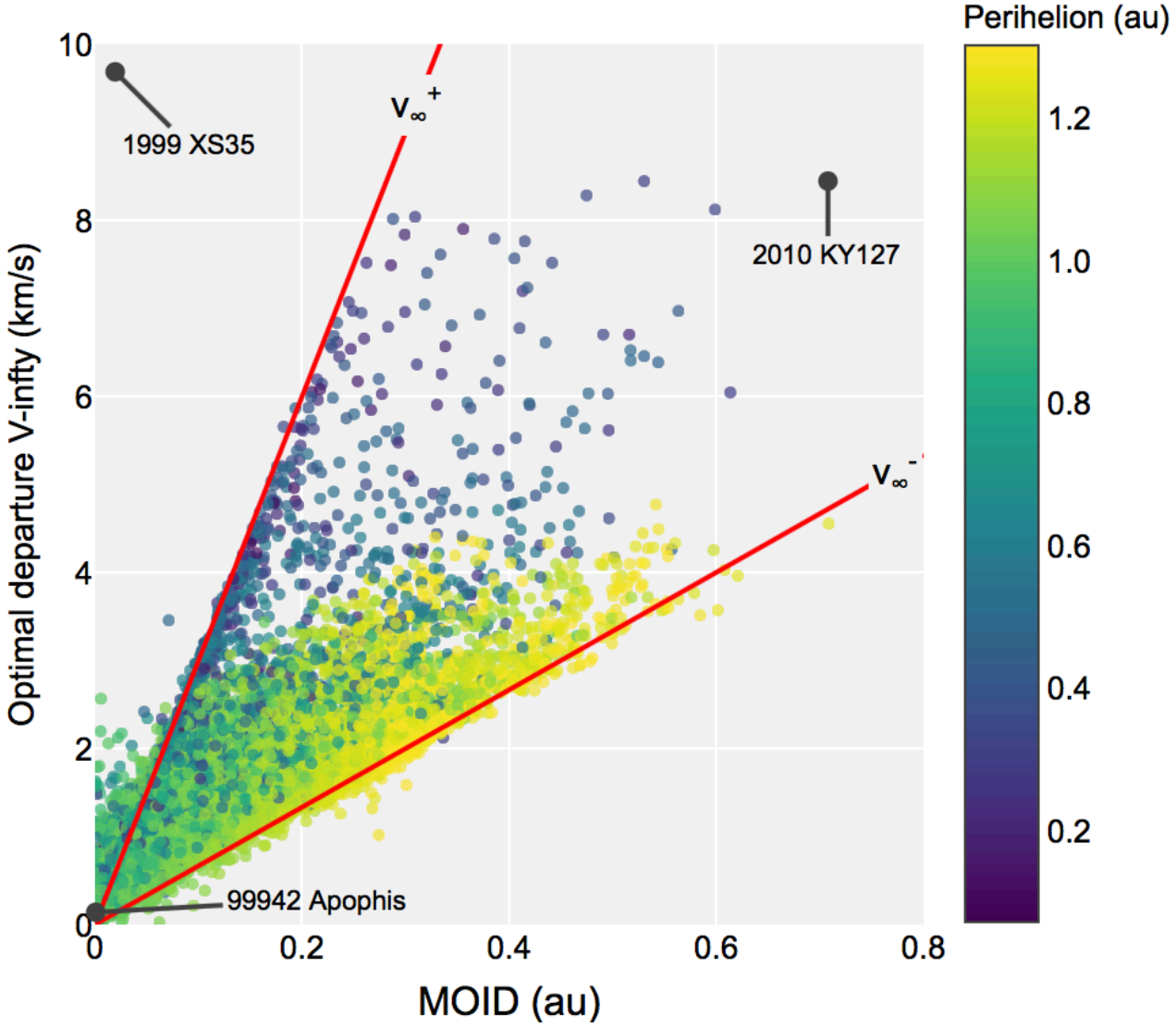
Statistics from Database

Distribution of Optimal Departure C_3



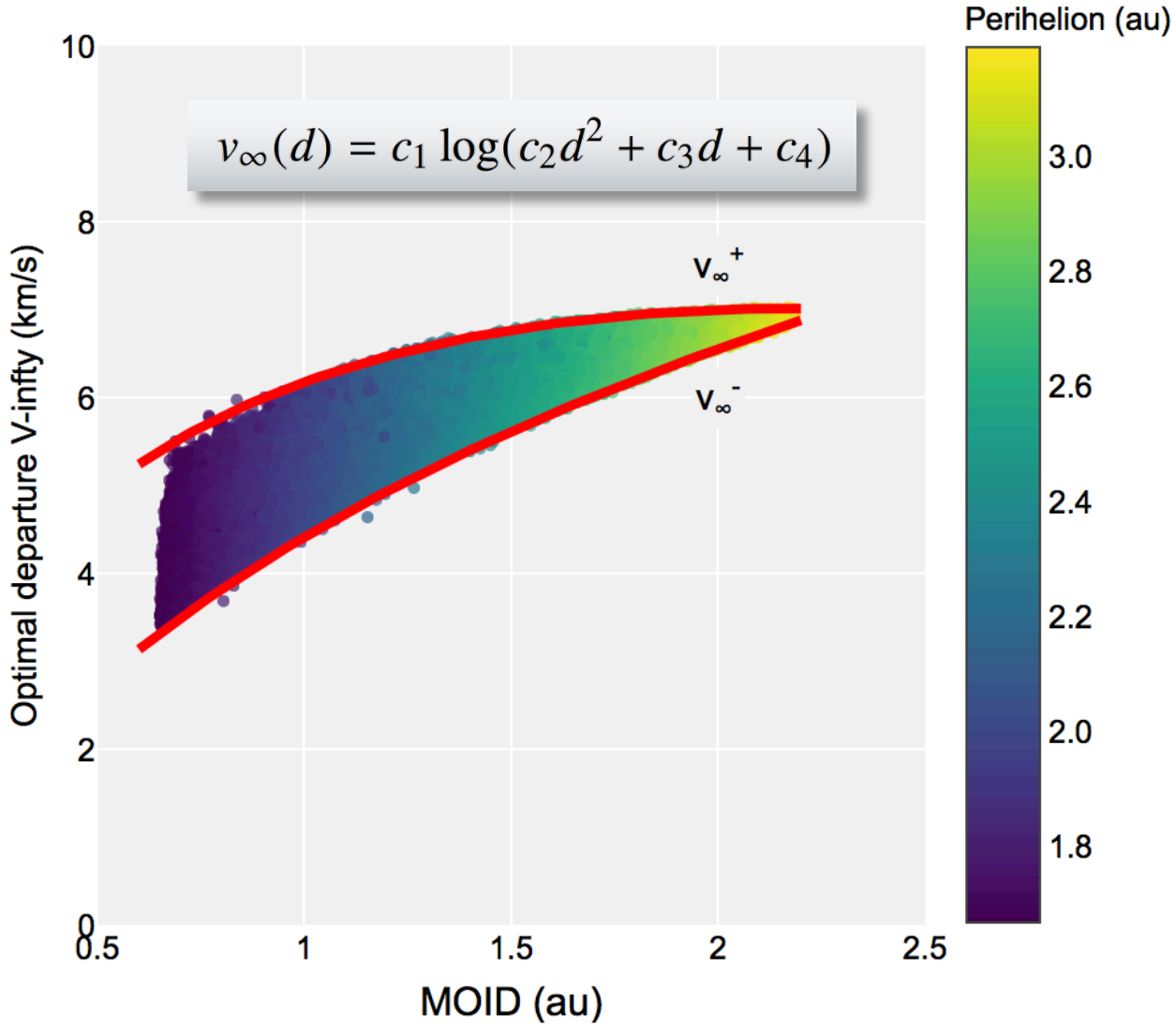
Statistics from Database

Near-Earth Asteroids



Statistics from Database

Main-Belt Asteroids

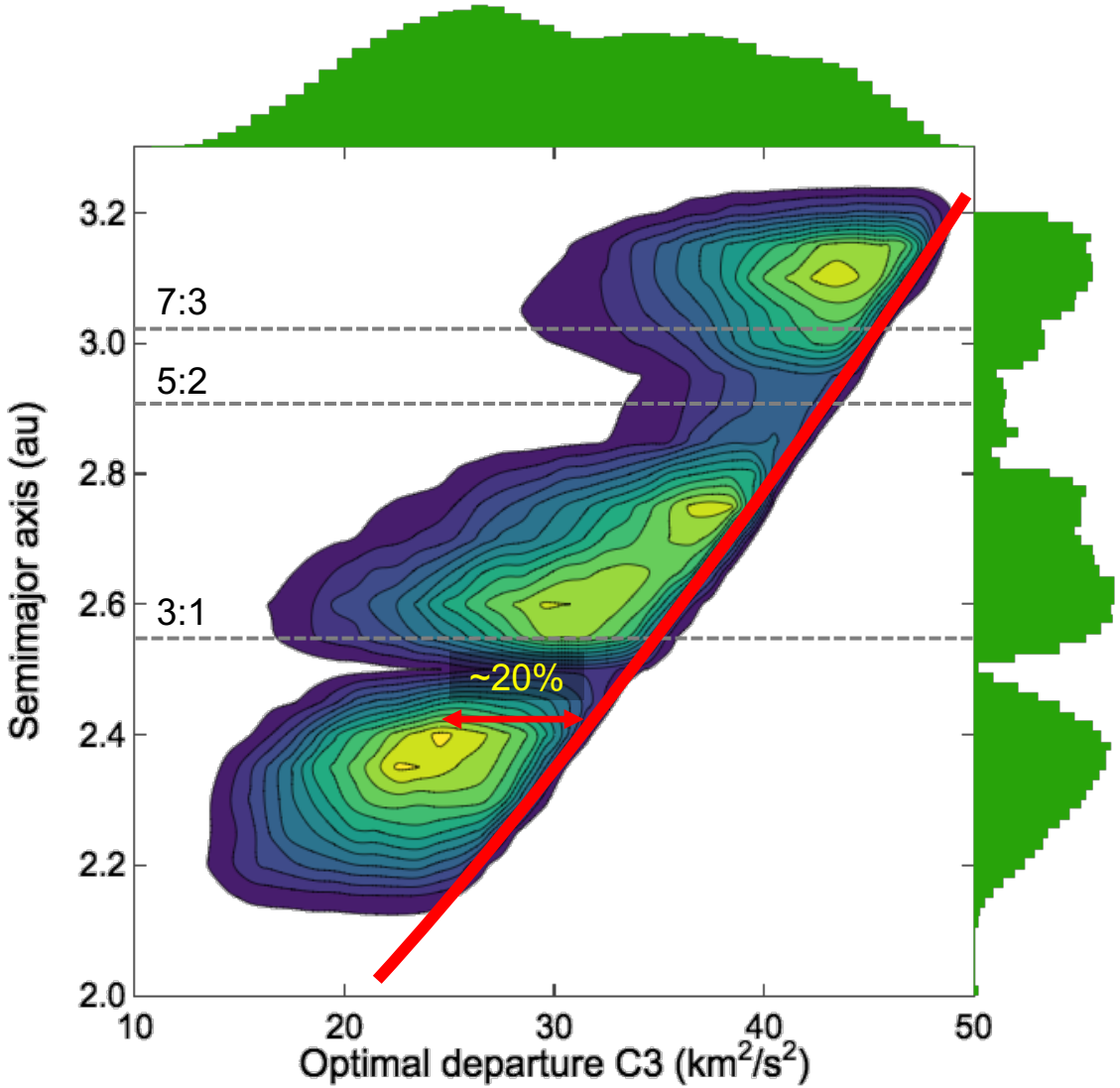


Statistics from Database

Main-Belt Asteroids

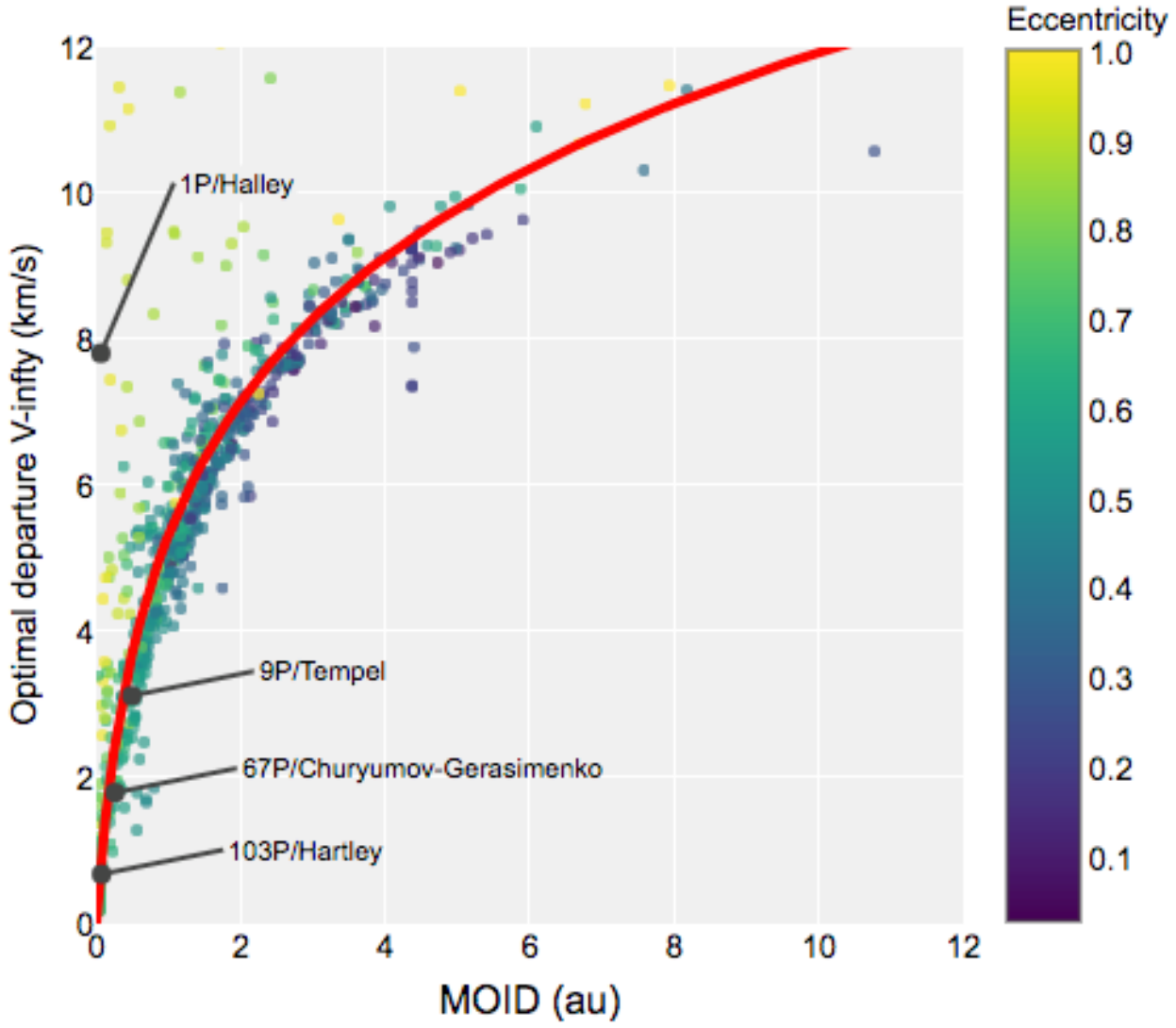
Kirkwood Gaps

Hohmann Approx.



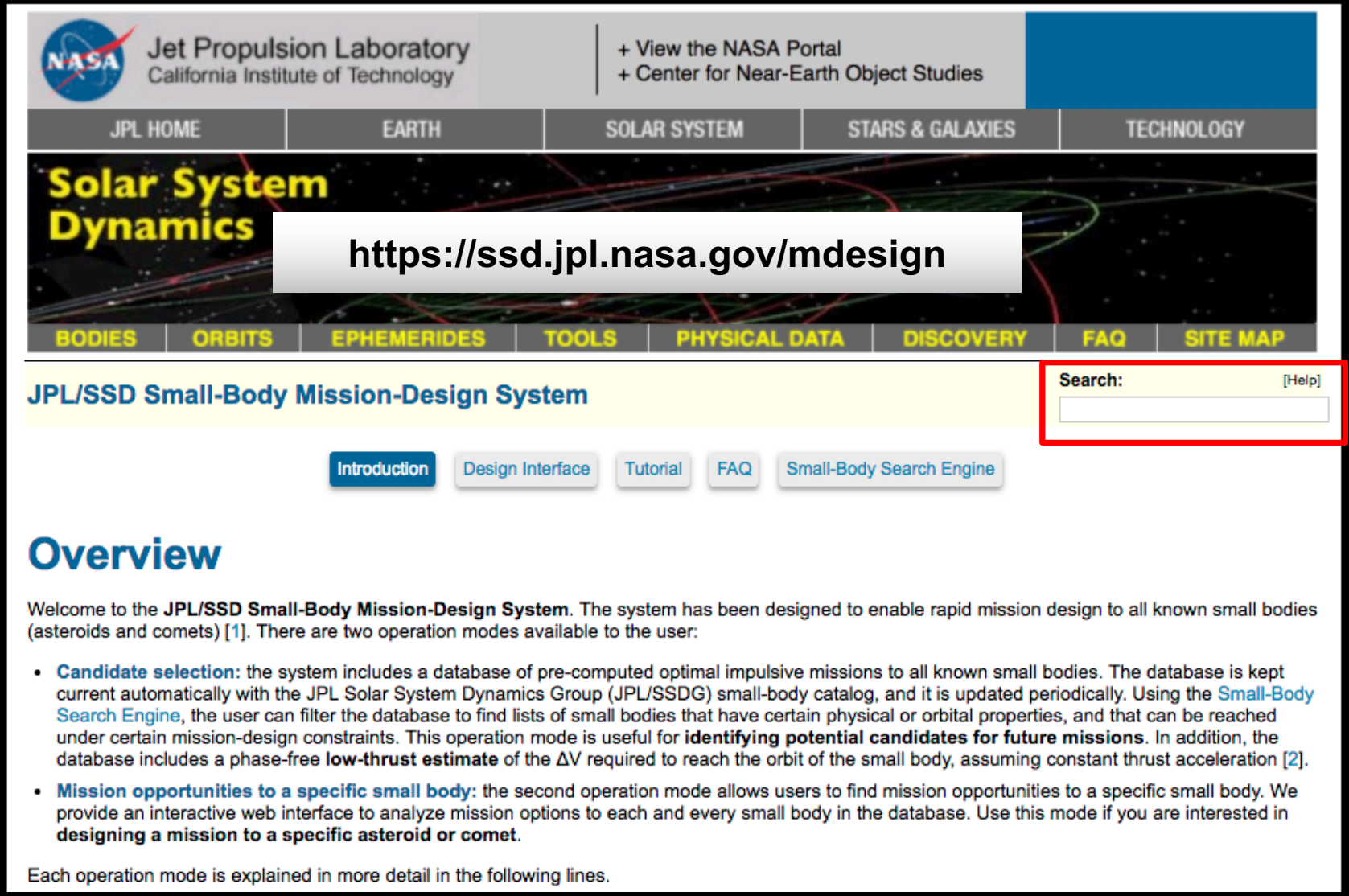
Statistics from Database

Comets



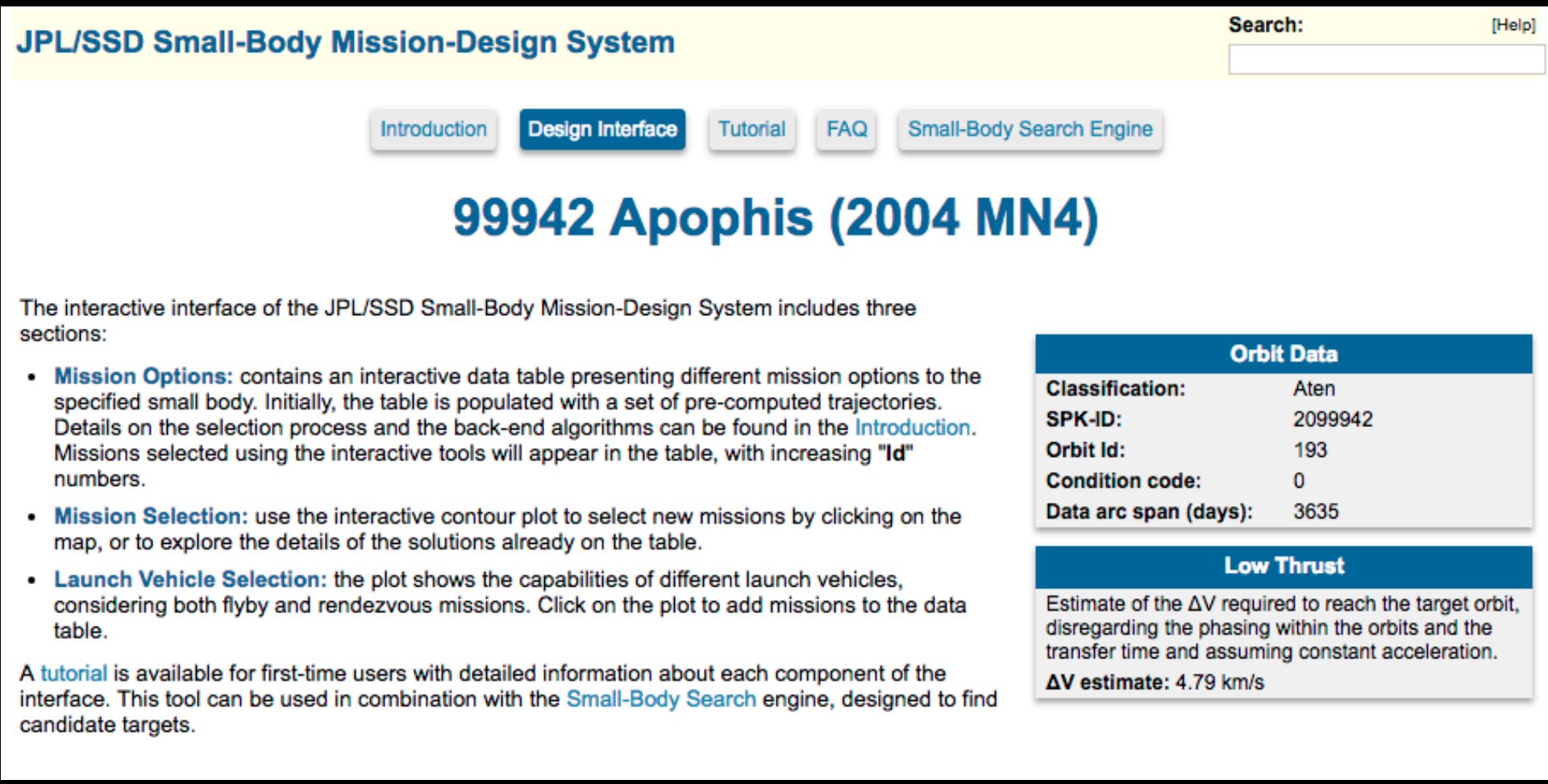
Interactive Web Interface

Introduction



Interactive Web Interface

Static Information



Interactive Web Interface

Table of Selected Missions

Mission Options:

The following table lists relevant mission options. Each mission is assigned a unique "**Id**" to distinguish it from the rest. Initially, it contains a set of pre-selected solutions that capture the optimal launch opportunities (minimizing the departure C3). The table presents additional mission options including minimum time of flight and minimum arrival V-infinity. Switch to **Mass mode** to see launch-vehicle capabilities. Order by decreasing "**Id**" (default) to see the new records on top.

Use the interactive tools Mission Selection and Launch Vehicle Selection to add missions to the table by simply clicking on the plots. Selected trajectories can be **plotted** in the ICRF system, using the Ecliptic at J2000 as the reference plane.

Download | Select all | Deselect all | Plot trajectories | Delete selected | ΔV mode | Mass mode | Show 10 entries

Id	Departure date (cal)	Departure date (MJD)	Arrival date (cal)	Arrival date (MJD)	TOF (days)	C3 (km²/s²)	V∞ dep. (km/s)	V∞ arr. (km/s)	Total ΔV (km/s)	Phase angle (deg)	Dist. Earth (au)	Pump angle (deg)	SEP angle (deg)	DLA (deg)
863	2028-08-25	62008	2029-04-12	62238	230	0.0	0.1	5.9	6.0	24.7	0.01	82.6	156.6	41.3
862	2028-07-31	61983	2029-04-12	62238	255	0.0	0.1	5.8	6.0	24.7	0.01	82.5	156.6	43.0
861	2028-12-18	62123	2029-04-12	62238	115	0.0	0.1	6.0	6.2	24.1	0.01	82.4	156.6	-39.9
860	2029-01-17	62153	2029-04-12	62238	85	0.0	0.2	6.1	6.2	24.3	0.01	82.2	156.6	-38.8
859	2028-11-23	62098	2029-04-12	62238	140	0.0	0.2	6.0	6.1	23.8	0.01	82.5	156.6	-42.3
858	2028-01-18	61788	2029-04-12	62238	450	0.1	0.2	5.8	6.0	24.5	0.01	82.8	156.6	7.7
857	2028-02-17	61818	2029-04-12	62238	420	0.1	0.2	5.9	6.1	24.2	0.01	83.2	156.6	-1.6
856	2028-05-27	61918	2029-04-12	62238	320	0.1	0.3	5.6	5.9	25.0	0.01	82.0	156.6	38.2
855	2020-01-20	58868	2021-04-19	59323	455	0.1	0.3	6.1	6.4	24.6	0.16	81.3	89.6	-37.1
854	2020-06-23	59023	2021-04-19	59323	300	0.1	0.3	5.2	5.5	28.8	0.16	77.8	89.6	31.5

Showing 1 to 10 of 863 entries

Previous 1 2 3 4 5 … 87 Next

Interactive Web Interface

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Download | Select all | Deselect all | Plot trajectories | Delete selected | ΔV mode | Mass mode | Show 10 entries

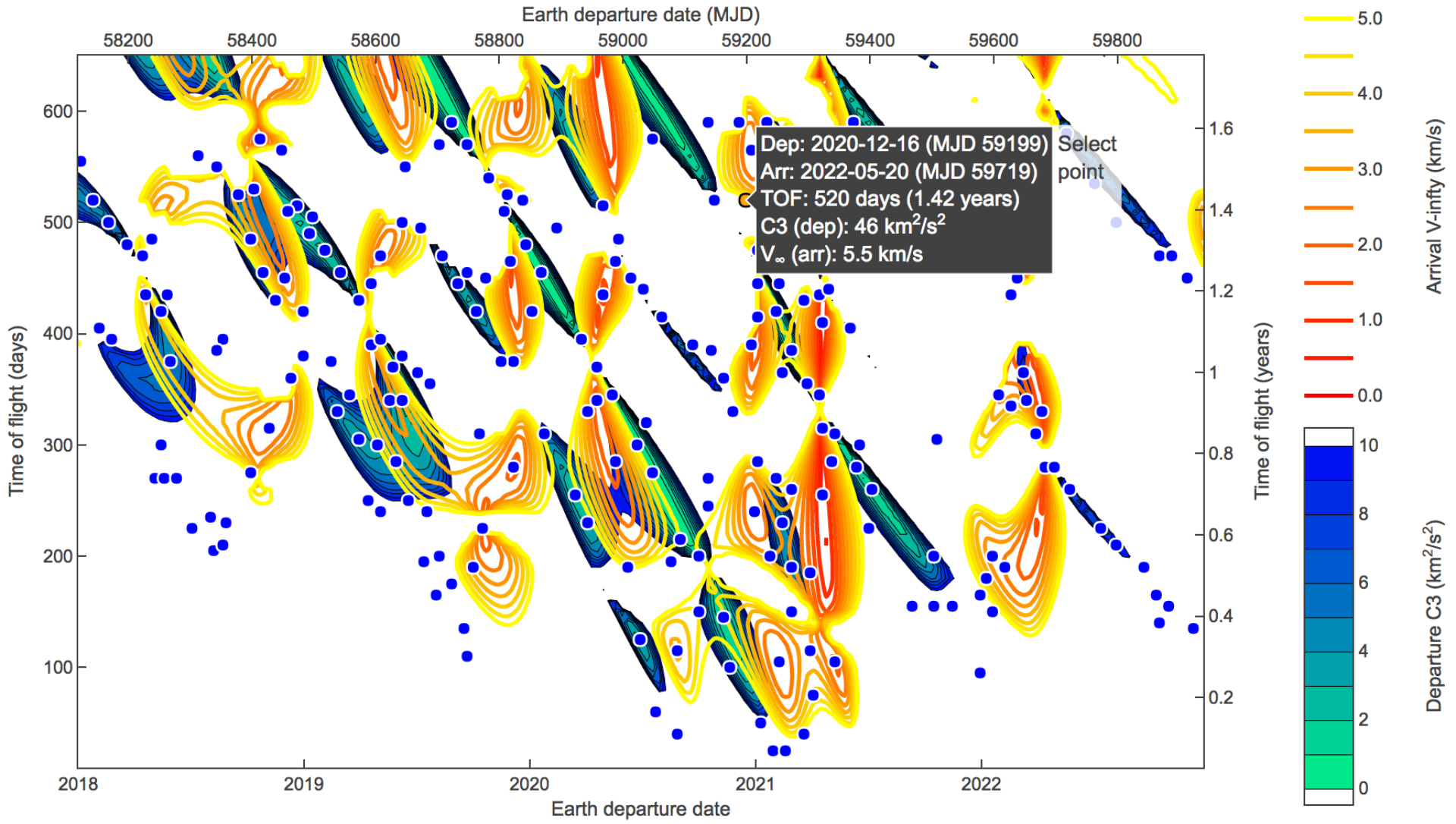
Id	Atlas V (531) (kg)		Atlas V (551) (kg)		Falcon 9 (kg)		Falcon Heavy (kg)		Delta IV-H (kg)		SLS 1B (kg)		SLS 2 (kg)	
	Flyby	Rdzvs	Flyby	Rdzvs	Flyby	Rdzvs	Flyby	Rdzvs	Flyby	Rdzvs	Flyby	Rdzvs	Flyby	Rdzvs
863	4935	760	6100	940	3305	510	12420	1915	10180	1570	22735	3505	52315	8075
862	4935	770	6100	955	3305	515	12420	1945	10180	1595	22735	3560	52315	8200
861	4935	725	6100	895	3305	485	12420	1820	10180	1490	22735	3335	52315	7680
860	4935	710	6100	875	3305	475	12420	1785	10180	1460	22730	3270	52315	7525
859	4935	735	6100	910	3305	490	12420	1855	10180	1520	22730	3395	52315	7810
858	4935	785	6095	970	3300	525	12415	1975	10175	1620	22720	3615	52295	8325
857	4930	750	6095	925	3300	500	12415	1890	10170	1545	22715	3455	52290	7960
856	4930	820	6095	1015	3300	550	12410	2075	10170	1700	22710	3795	52280	8740
855	4930	705	6095	870	3300	470	12410	1780	10170	1455	22710	3255	52280	7500
854	4930	930	6095	1150	3300	620	12410	2340	10170	1920	22705	4285	52275	9875

Showing 1 to 10 of 863 entries

Previous 1 2 3 4 5 … 87 Next

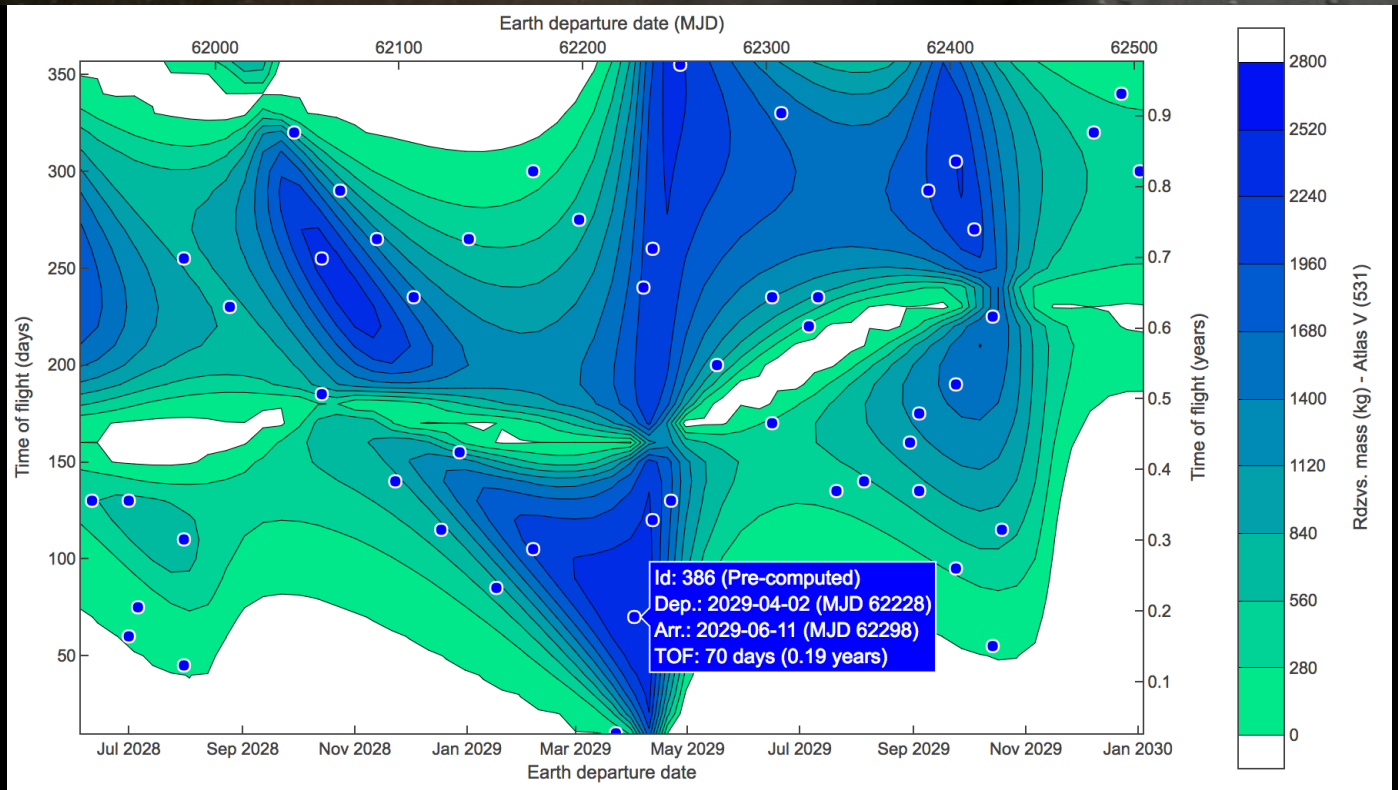
Interactive Web Interface

Interactive Pork-Chop Plot



Interactive Web Interface

Interactive Pork-Chop Plot



HOVER INFO: Id: 386 (Pre-computed)

Departure date		Arrival date		TOF	C3	V_∞ dep.	V_∞ arr.	Total ΔV	Phase angle	Dist. Earth	Pump angle	SEP angle	Launch declin.
(cal)	(MJD)	(cal)	(MJD)	(days)	(km^2/s^2)	(km/s)	(km/s)	(km/s)	(deg)	(au)	(deg)	(deg)	(deg)
2029-04-02	62228	2029-06-11	62298	70	19.8	4.5	0.9	5.4	95.0	0.23	162.7	52.8	17.1

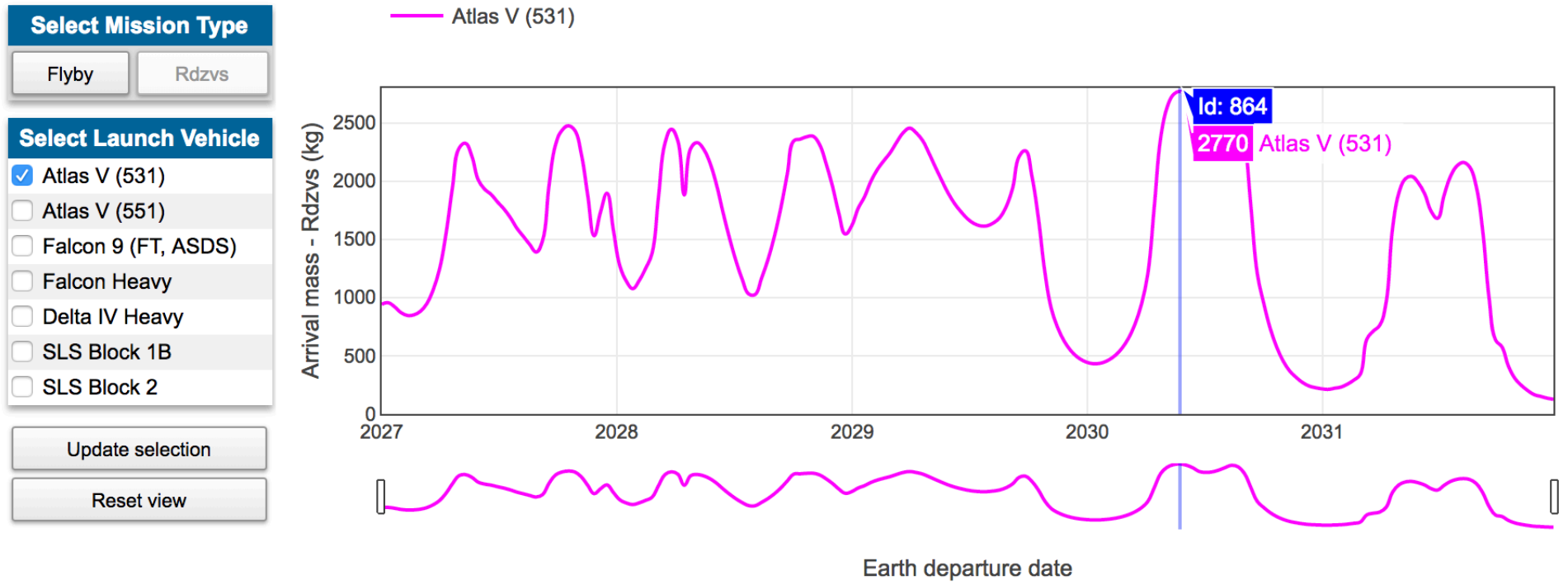
Atlas V (531) (kg)		Atlas V (551) (kg)		Falcon 9 (kg)		Falcon Heavy (kg)		Delta IV-H (kg)		SLS 1B (kg)		SLS 2 (kg)	
Flyby	Rdzvs	Flyby	Rdzvs	Flyby	Rdzvs	Flyby	Rdzvs	Flyby	Rdzvs	Flyby	Rdzvs	Flyby	Rdzvs
3295	2450	4150	3090	-	-	7740	5760	7015	5220	14880	11075	38610	28735

Interactive Web Interface

Launch –Vehicle Selection

Launch-Vehicle Selection:

The figure displays the maximum mass of the spacecraft that will reach the target body when launched on a certain date. Use the control panels to select the mission type (flyby or rendezvous), and to update the list of launch vehicles. Click on the plot to add missions to the Mission Options table. Zoom in using the slider under the figure or by clicking and dragging on the chart.



Conclusions

Statistical results

- Analytic estimate of the limits on the departure V-infinity.

Candidate Selection

- Find list of candidate targets in seconds.
- Combined with **physical** + **orbital** parameters.
- Database of pre-computed solutions, publicly available.
- DB is kept current automatically.

Preliminary Design

- Use web interface to select dates and launch vehicle.
- Save data for post-processing.
- Fast access to latest ephemeris.

Thank you!

Jet Propulsion Laboratory
California Institute of Technology

javier.roa@jpl.nasa.gov